

NODE=B019

 **$\Delta(1600) \frac{3}{2}^+$** 

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+) \text{ Status: } ***$

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The various analyses are not in good agreement.

 **$\Delta(1600)$  BREIT-WIGNER MASS**

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>1500 to 1700 (<math>\approx 1600</math>) OUR ESTIMATE</b>			
1510 $\pm$ 20	ANISOVICH	12A	DPWA Multichannel
1600 $\pm$ 50	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
1522 $\pm$ 13	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1626 $\pm$ 8	SHRESTHA	12A	DPWA Multichannel
1650 $\pm$ 40	HORN	08A	DPWA Multichannel
1667 $\pm$ 1	PENNER	02C	DPWA Multichannel
1687 $\pm$ 44	VRANA	00	DPWA Multichannel
1672 $\pm$ 15	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
1706	LI	93	IPWA $\gamma N \rightarrow \pi N$
1706 $\pm$ 10	MANLEY	92	IPWA $\pi N \rightarrow \pi N \& N\pi\pi$
1690	BARNHAM	80	IPWA $\pi N \rightarrow N\pi\pi$
1560	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
1640	<sup>2</sup> LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

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 **$\Delta(1600)$  BREIT-WIGNER WIDTH**

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>220 to 420 (<math>\approx 320</math>) OUR ESTIMATE</b>			
220 $\pm$ 45	ANISOVICH	12A	DPWA Multichannel
300 $\pm$ 100	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
220 $\pm$ 40	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
225 $\pm$ 18	SHRESTHA	12A	DPWA Multichannel
530 $\pm$ 60	HORN	08A	DPWA Multichannel
397 $\pm$ 10	PENNER	02C	DPWA Multichannel
493 $\pm$ 75	VRANA	00	DPWA Multichannel
315 $\pm$ 20	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
215	LI	93	IPWA $\gamma N \rightarrow \pi N$
430 $\pm$ 73	MANLEY	92	IPWA $\pi N \rightarrow \pi N \& N\pi\pi$
250	BARNHAM	80	IPWA $\pi N \rightarrow N\pi\pi$
180	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
300	<sup>2</sup> LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

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 **$\Delta(1600)$  POLE POSITION**

REAL PART VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>1460 to 1560 (<math>\approx 1510</math>) OUR ESTIMATE</b>			
1498 $\pm$ 25	ANISOVICH	12A	DPWA Multichannel
1457	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
1550	<sup>3</sup> HOEHLER	93	SPED $\pi N \rightarrow \pi N$
1550 $\pm$ 40	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
1599	SHRESTHA	12A	DPWA Multichannel
1510 $^{+20}_{-50}$	HORN	08A	DPWA Multichannel
1599	VRANA	00	DPWA Multichannel
1675	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
1612	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
1609 or 1610	<sup>4</sup> LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
1541 or 1542	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

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**-2×IMAGINARY PART**

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>200 to 350 (<math>\approx 275</math>) OUR ESTIMATE</b>			
230±50	ANISOVICH	12A	DPWA Multichannel
400	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
200±60	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
211	SHRESTHA	12A	DPWA Multichannel
230±40	HORN	08A	DPWA Multichannel
312	VRANA	00	DPWA Multichannel
386	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
230	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
323 or 325	<sup>4</sup> LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
178 or 178	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

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 **$\Delta(1600)$  ELASTIC POLE RESIDUE****MODULUS | $r$ |**

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
11±6	ANISOVICH	12A	DPWA Multichannel
44	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
17±4	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
52	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
16	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

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**PHASE  $\theta$** 

VALUE (°)	DOCUMENT ID	TECN	COMMENT
-160±33	ANISOVICH	12A	DPWA Multichannel
+147	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
-150±30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
+ 14	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
- 73	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

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 **$\Delta(1600)$  INELASTIC POLE RESIDUE**

The “normalized residue” is the residue divided by  $\Gamma_{pole}/2$ .

**Normalized residue in  $N\pi \rightarrow \Delta(1600) \rightarrow \Delta\pi, P\text{-wave}$** 

MODULUS (%)	PHASE (°)	DOCUMENT ID	TECN	COMMENT
14±10	154 ± 40	ANISOVICH	12A	DPWA Multichannel

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**Normalized residue in  $N\pi \rightarrow \Delta(1600) \rightarrow \Delta\pi, F\text{-wave}$** 

MODULUS (%)	DOCUMENT ID	TECN	COMMENT
1.0±0.5	ANISOVICH	12A	DPWA Multichannel

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 **$\Delta(1600)$  DECAY MODES**

The following branching fractions are our estimates, not fits or averages.

Mode	Fraction ( $\Gamma_i/\Gamma$ )	
$\Gamma_1 N\pi$	10–25 %	DESIG=1;OUR EST
$\Gamma_2 \Sigma K$		DESIG=2
$\Gamma_3 N\pi\pi$	75–90 %	DESIG=11;OUR EST
$\Gamma_4 \Delta\pi$	40–70 %	DESIG=22;OUR EST
$\Gamma_5 \Delta(1232)\pi, P\text{-wave}$		DESIG=3
$\Gamma_6 \Delta(1232)\pi, F\text{-wave}$		DESIG=4
$\Gamma_7 N\rho$	<25 %	DESIG=23;OUR EST
$\Gamma_8 N\rho, S=1/2, P\text{-wave}$		DESIG=5
$\Gamma_9 N\rho, S=3/2, P\text{-wave}$		DESIG=6
$\Gamma_{10} N\rho, S=3/2, F\text{-wave}$		DESIG=7
$\Gamma_{11} N(1440)\pi$	10–35 %	DESIG=24;OUR EST
$\Gamma_{12} N(1440)\pi, P\text{-wave}$		DESIG=8
$\Gamma_{13} N\gamma$	0.001–0.035 %	DESIG=25;OUR EST
$\Gamma_{14} N\gamma, \text{ helicity}=1/2$	0.0–0.02 %	DESIG=9;OUR EST
$\Gamma_{15} N\gamma, \text{ helicity}=3/2$	0.001–0.015 %	DESIG=10;OUR EST

**Δ(1600) BRANCHING RATIOS** **$\Gamma(N\pi)/\Gamma_{\text{total}}$** 

VALUE (%)

**10 to 25 OUR ESTIMATE**

	DOCUMENT ID	TECN	COMMENT	$\Gamma_1/\Gamma$
12±5	ANISOVICH	12A	DPWA Multichannel	
18±4	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$	
21±6	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
8±2	SHRESTHA	12A	DPWA Multichannel	
10±3	HORN	08A	DPWA Multichannel	
13±1	PENNER	02C	DPWA Multichannel	
28±5	VRANA	00	DPWA Multichannel	
12±2	MANLEY	92	IPWA $\pi N \rightarrow \pi N & N\pi\pi$	

 **$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$  in  $N\pi \rightarrow \Delta(1600) \rightarrow \Sigma K$** 

VALUE

**-0.36 to -0.28 OUR ESTIMATE**

	DOCUMENT ID	TECN	COMMENT	$(\Gamma_1\Gamma_2)^{1/2}/\Gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.006 to 0.042	5 DEANS	75	DPWA $\pi N \rightarrow \Sigma K$	

Note: Signs of couplings from  $\pi N \rightarrow N\pi\pi$  analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the  $\Delta(1620)$   $S_{31}$  coupling to  $\Delta(1232)\pi$ .

 **$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$  in  $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi$ , P-wave**

VALUE

**+0.27 to +0.33 OUR ESTIMATE**

	DOCUMENT ID	TECN	COMMENT	$(\Gamma_1\Gamma_5)^{1/2}/\Gamma$
+0.24±0.05	BARNHAM	80	IPWA $\pi N \rightarrow N\pi\pi$	
+0.34	1,6 LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$	
+0.30	2 LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
+0.29±0.02	MANLEY	92	IPWA $\pi N \rightarrow \pi N & N\pi\pi$	

 **$\Gamma(\Delta(1232)\pi, P\text{-wave})/\Gamma_{\text{total}}$** 

VALUE (%)

	DOCUMENT ID	TECN	COMMENT	$\Gamma_5/\Gamma$
78±6	ANISOVICH	12A	DPWA Multichannel	
59±10	VRANA	00	DPWA Multichannel	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
70±3	SHRESTHA	12A	DPWA Multichannel	

 **$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$  in  $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi$ , F-wave**

VALUE

**-0.15 to -0.03 OUR ESTIMATE**

	DOCUMENT ID	TECN	COMMENT	$(\Gamma_1\Gamma_6)^{1/2}/\Gamma$
-0.07	1,6 LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$	

 **$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$  in  $N\pi \rightarrow \Delta(1600) \rightarrow N\rho, S=1/2$ , P-wave**

VALUE

	DOCUMENT ID	TECN	COMMENT	$(\Gamma_1\Gamma_8)^{1/2}/\Gamma$
+0.10	1,6 LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$	

 **$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$  in  $N\pi \rightarrow \Delta(1600) \rightarrow N\rho, S=3/2$ , P-wave**

VALUE

	DOCUMENT ID	TECN	COMMENT	$(\Gamma_1\Gamma_9)^{1/2}/\Gamma$
+0.10	1,6 LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$	

 **$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$  in  $N\pi \rightarrow \Delta(1600) \rightarrow N(1440)\pi$ , P-wave**

VALUE

	DOCUMENT ID	TECN	COMMENT	$(\Gamma_1\Gamma_{12})^{1/2}/\Gamma$
+0.15 to +0.23 OUR ESTIMATE				
+0.23±0.04	BARNHAM	80	IPWA $\pi N \rightarrow N\pi\pi$	

• • • We do not use the following data for averages, fits, limits, etc. • • •

	DOCUMENT ID	TECN	COMMENT	$(\Gamma_1\Gamma_{12})^{1/2}/\Gamma$
+0.16±0.02	MANLEY	92	IPWA $\pi N \rightarrow \pi N & N\pi\pi$	

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NODE=B019R2  
NODE=B019R2  
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NODE=B019310

NODE=B019R3  
NODE=B019R3  
→ UNCHECKED ←

NODE=B019R8  
NODE=B019R8

NODE=B019R4  
NODE=B019R4  
→ UNCHECKED ←

NODE=B019R5  
NODE=B019R5

NODE=B019R6  
NODE=B019R6

NODE=B019R7  
NODE=B019R7  
→ UNCHECKED ←

$\Gamma(N(1440)\pi)/\Gamma_{\text{total}}$ 

VALUE (%)	DOCUMENT ID	TECN	COMMENT	$\Gamma_{11}/\Gamma$
13±4	VRANA 00	DPWA	Multichannel	NODE=B019R9 NODE=B019R9
• • • We do not use the following data for averages, fits, limits, etc. • • •				
22±3	SHRESTHA 12A	DPWA	Multichannel	

 $\Delta(1600)$  PHOTON DECAY AMPLITUDES

Papers on  $\gamma N$  amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G **33** 1 (2006).

 $\Delta(1600) \rightarrow N\gamma$ , helicity-1/2 amplitude  $A_{1/2}$ 

VALUE ( $\text{GeV}^{-1/2}$ )	DOCUMENT ID	TECN	COMMENT	$\Gamma_{11}/\Gamma$
<b>-0.023±0.020 OUR ESTIMATE</b>				
-0.050±0.009	ANISOVICH 12A	DPWA	Multichannel	NODE=B019235
-0.018±0.015	ARNDT 96	IPWA	$\gamma N \rightarrow \pi N$	NODE=B019235
-0.039±0.030	CRAWFORD 83	IPWA	$\gamma N \rightarrow \pi N$	
-0.046±0.013	AWAJI 81	DPWA	$\gamma N \rightarrow \pi N$	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.006±0.005	SHRESTHA 12A	DPWA	Multichannel	
0.0	PENNER 02D	DPWA	Multichannel	
-0.026±0.002	LI 93	IPWA	$\gamma N \rightarrow \pi N$	
-0.200	7 WADA 84	DPWA	Compton scattering	
0.000±0.030	BARBOUR 78	DPWA	$\gamma N \rightarrow \pi N$	

 $\Delta(1600) \rightarrow N\gamma$ , helicity-3/2 amplitude  $A_{3/2}$ 

VALUE ( $\text{GeV}^{-1/2}$ )	DOCUMENT ID	TECN	COMMENT	$\Gamma_{11}/\Gamma$
<b>-0.009±0.021 OUR ESTIMATE</b>				
-0.040±0.012	ANISOVICH 12A	DPWA	Multichannel	NODE=B019A2 NODE=B019A2
-0.025±0.015	ARNDT 96	IPWA	$\gamma N \rightarrow \pi N$	→ UNCHECKED ←
-0.013±0.014	CRAWFORD 83	IPWA	$\gamma N \rightarrow \pi N$	
0.025±0.031	AWAJI 81	DPWA	$\gamma N \rightarrow \pi N$	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.052±0.008	SHRESTHA 12A	DPWA	Multichannel	
-0.024	PENNER 02D	DPWA	Multichannel	
-0.016±0.002	LI 93	IPWA	$\gamma N \rightarrow \pi N$	
0.023	WADA 84	DPWA	Compton scattering	
0.000±0.045	BARBOUR 78	DPWA	$\gamma N \rightarrow \pi N$	

 $\Delta(1600)$  FOOTNOTES

<sup>1</sup> LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to  $\pi N \rightarrow N\pi\pi$  data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

<sup>2</sup> From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

<sup>3</sup> See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of  $N$  and  $\Delta$  resonances as determined from Argand diagrams of  $\pi N$  elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

<sup>4</sup> LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to  $\pi N \rightarrow N\pi\pi$  data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

<sup>5</sup> The range given is from the four best solutions. DEANS 75 disagrees with  $\pi^+ p \rightarrow \Sigma^+ K^+$  data of WINNIK 77 around 1920 MeV.

<sup>6</sup> LONGACRE 77 considers this coupling to be well determined.

<sup>7</sup> WADA 84 is inconsistent with other analyses — see the Note on  $N$  and  $\Delta$  Resonances.

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NODE=B019A1

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NODE=B019A2

NODE=B019A2

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NODE=B019

NODE=B019;LINKAGE=L7

NODE=B019;LINKAGE=L5

NODE=B010;LINKAGE=H9

NODE=B019;LINKAGE=L8

NODE=B019;LINKAGE=C

NODE=B019;LINKAGE=X

NODE=B019;LINKAGE=P

NODE=B019

NODE=B019

REFID=54041

REFID=54862

REFID=52706

REFID=52567

REFID=51535

REFID=51004

REFID=49129

REFID=49130

REFID=47593

REFID=44675

REFID=44535

REFID=43821

 $\Delta(1600)$  REFERENCES

For early references, see Physics Letters **111B** 1 (1982).

ANISOVICH 12A	EPJ A48 15	A.V. Anisovich <i>et al.</i>	(BONN, PNPI) (KSU)
SHRESTHA 12A	PR C86 055203	M. Shrestha, D.M. Manley	
HORN 08A	EPJ A38 173	I. Horn <i>et al.</i>	(CB-ELSA Collab.)
Also	PRI 101 202002	I. Horn <i>et al.</i>	(CB-ELSA Collab.)
ARNDT 06	PR C74 045205	R.A. Arndt <i>et al.</i>	(GWU)
PDG 06	JPG 33 1	W.-M. Yao <i>et al.</i>	(PDG Collab.)
PENNER 02C	PR C66 05211	G. Penner, U. Mosel	(GIES)
PENNER 02D	PR C66 055212	G. Penner, U. Mosel	(GIES)
VRANA 00	PRPL 328 181	T.P. Vrana, S.A. Dytman,, T.-S.H. Lee	(PITT+)
ARNDT 96	PR C53 430	R.A. Arndt, I.I. Strakovsky, R.L. Workman	(VPI)
ARNDT 95	PR C52 2120	R.A. Arndt <i>et al.</i>	(VPI, BRCO)
HOEHLER 93	$\pi N$ Newsletter 9 1	G. Hohler	(KARL)

LI	93	PR C47 2759	Z.J. Li <i>et al.</i>	(VPI)	REFID=43327
MANLEY	92	PR D45 4002	D.M. Manley, E.M. Saleski	(KSA) IJP	REFID=41535
Also		PR D30 904	D.M. Manley <i>et al.</i>	(VPI)	REFID=30071
ARNDT	91	PR D43 2131	R.A. Arndt <i>et al.</i>	(VPI, TELE) IJP	REFID=41467
WADA	84	NP B247 313	Y. Wada <i>et al.</i>	(INUS)	REFID=30072
CRAWFORD	83	NP B211 1	R.L. Crawford, W.T. Morton	(GLAS)	REFID=30070
PDG	82	PL 111B 1	M. Roos <i>et al.</i>	(HELS, CIT, CERN)	REFID=41167
AWAJI	81	Bonn Conf. 352	N. Awaji, R. Kajikawa	(NAGO)	REFID=30067
Also		NP B197 365	K. Fujii <i>et al.</i>	(NAGO)	REFID=30068
BARNHAM	80	NP B168 243	K.W.J. Barnham <i>et al.</i>	(LOIC)	REFID=31072
CUTKOSKY	80	Toronto Conf. 19	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP	REFID=30064
Also		PR D20 2839	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP	REFID=40096
HOEHLER	79	PDAT 12-1	G. Hohler <i>et al.</i>	(KARLT) IJP	REFID=30058
Also		Toronto Conf. 3	R. Koch	(KARLT) IJP	REFID=30859
BARBOUR	78	NP B141 253	I.M. Barbour, R.L. Crawford, N.H. Parsons	(GLAS)	REFID=30053
LONGACRE	78	PR D17 1795	R.S. Longacre <i>et al.</i>	(LBL, SLAC)	REFID=30054
LONGACRE	77	NP B122 493	R.S. Longacre, J. Dolbeau	(SACL) IJP	REFID=30051
Also		NP B108 365	J. Dolbeau <i>et al.</i>	(SACL) IJP	REFID=30052
WINNIK	77	NP B128 66	M. Winnik <i>et al.</i>	(HAIF) I	REFID=30378
DEANS	75	NP B96 90	S.R. Deans <i>et al.</i>	(SFLA, ALAH) IJP	REFID=30383
LONGACRE	75	PL 55B 415	R.S. Longacre <i>et al.</i>	(LBL, SLAC) IJP	REFID=30047